CLAIMS

WHAT IS CLAIMED IS:

1. A method for scrubbing sulfur dioxide from a flue gas stream, the flue gas stream having an initial sulfur dioxide concentration, comprising the following steps:

contacting the flue gas stream with a plurality of aqueous ammonia liquor streams; and

forming a scrubber product stream, the scrubber product stream comprising ammonium bisulfite and ammonium sulfite.

2. The method of claim 1, wherein the aqueous ammonia liquor stream comprises water and ammonia.

3. The method as described in claim 1, wherein each of the aqueous ammonia liquor streams has a pH of between 5.0 and 6.0.

4. The method as described in claim 3, wherein each of the aqueous ammonia liquor streams has a pH of between 5.4 and 5.8.

5. The method of claim 1, wherein contacting the flue gas stream with N number of aqueous ammonia liquor streams is accomplished through the use of liquid distributors.

6. The method of claim 5, wherein the liquid distributors are nozzles.

7. The method as described in claim 1, wherein the total dissolved solids of the scrubber product stream are about 50 to about 90% ammonium bisulfite, by weight.

8. The method as described in claim 1, wherein the total dissolved solids of the scrubber product stream are about 5 to about 45% sulfite, by weight.

9. The method as described in claim 1, further comprising after contacting the flue gas stream with a plurality of aqueous ammonia liquor streams:

producing a flue gas effluent stream, the flue gas effluent stream having a final sulfur dioxide concentration.

10. The method as described in claim 9, wherein the flue gas effluent stream has a final sulfur dioxide concentration of less than 100 ppm by weight.

11. The method as described in claim 9, wherein the flue gas effluent stream has a final sulfur dioxide concentration of less than 1% of the flue gas initial sulfur dioxide concentration.

12. A method for scrubbing sulfur dioxide from a flue gas stream within a multistage scrubber with n number of stages, wherein N > 1 and further wherein n is an integer counter of stages having a value between 1 and N-1(1, 2, 3 . . . N-1), the flue gas stream having an initial sulfur concentration comprising:

forming each of the n numbered aqueous ammonia liquor streams by combining a water stream, an ammonia stream, a drain portion of a scrubber stage n+1 removal stream, and a recycle portion of the scrubber stage n removal stream, wherein each of the drain and recycle portions of each of the scrubber stage removal streams may range from 0 – 100% of the total of each of the scrubber stage removal streams.

forming the Nth aqueous ammonia liquor stream by combining a water stream, an ammonia stream, and a scrubber stage removal stream.

contacting the flue gas stream with each of the N number of aqueous ammonia liquor streams; and

forming a scrubber product stream, the scrubber product stream comprising ammonium sulfite and ammonium bisulfite.

13. The method as described in claim 12, wherein each of the aqueous ammonia liquor streams has a pH of between 5.0 and 6.0.

14. The method as described in claim 13, wherein each of the aqueous ammonia liquor streams has a pH of between 5.4 and 5.8.

15. The method of claim 12, wherein contacting the flue gas stream with N number of aqueous ammonia liquor streams is accomplished through the use of liquid distributors.

16. The method of claim 15, wherein the liquid distributors are nozzles.

17. The method as described in claim 12, wherein the total dissolved solids of the scrubber product stream are about 50 to about 90% ammonium bisulfite, by weight.

18. The method as described in claim 12, wherein the total dissolved solids of the scrubber product stream are about 5 to about 45% sulfite, by weight.

19. The method as described in claim 12, further comprising after contacting the flue gas stream with N number of aqueous ammonia liquor streams:

producing a flue gas effluent stream, the flue gas effluent stream having a final sulfur dioxide concentration.

20. The method as described in claim 19, wherein the flue gas effluent stream has a final sulfur dioxide concentration of less than 100 ppm by weight.

21. The method as described in claim 19, wherein the flue gas effluent stream has a final sulfur dioxide concentration of less than 1% of the flue gas initial sulfur dioxide concentration.

22. The method as described in claim 12, wherein N is equal to 4.

23. The method as described in claim 22, wherein the N-3 aqueous ammonia liquor stream has an ammonia concentration of about 30 to about 55% by weight.

24. The method as described in claim 22, wherein the N-2 aqueous ammonia liquor stream has an ammonia concentration of about 12 to about 22% by weight.

25. The method as described in claim 22, wherein the N-1 aqueous ammonia liquor stream has an ammonia concentration of about 5 to about 10% by weight.

26. The method as described in claim 22, wherein the Nth aqueous ammonia liquor stream has an ammonia concentration of about 0.5 to about 1.1%.

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27. A multistage scrubber for removing sulfur dioxide from flue gas comprising:

(a) a vertically-oriented shell, the shell having an upper end and a lower end, the shell further having a flue gas entry port and flue gas exit port, the shell further having an interior cavity, a vertical axis, and an interior surface;

(b) N number of liquid distributor headers within the interior cavity of the shell, so located such that the liquid distributor headers are capable of receiving fluid, wherein N is greater than 1 and wherein the liquid distribution headers are numbered from 1 to N;

(c) a plurality of liquid distributors, the liquid distributors in fluid communication with the liquid distributor headers and capable of distributing fluid from the liquid distributor headers to the interior cavity of the shell;

(d) N-1 number of scrubber stage separators numbered 2 to N along the vertical axis, each of the scrubber stage separators located in a plane substantially perpendicular to the vertical axis, each scrubber stage separator having an upper surface;

(e) a plurality of fluid exit ports, each fluid exit port capable of withdrawing liquid from the upper surface of a particular scrubber stage separator;

(f) N number of stages numbered 1 to N wherein each of the stages numbered 2 to N comprise the correspondingly numbered liquid distribution header, the correspondingly numbered scrubber stage separator, and at least one of the fluid exit ports and stage 1 comprises the correspondingly numbered liquid distribution header and at least one fluid exit port; and

(g) a scrubber product line, the scrubber product line capable of removing fluid from the multistage scrubber.

28. The multistage scrubber of claim 27 further comprising packing, the packing arranged within the interior cavity of the shell, the packing located above at least one of the scrubber stage separators.

29. The multistage scrubber of claim 28, wherein the packing is wire gauze packing.

30. The multistage scrubber of claim 28, wherein the packing has a pressure drop of less than 0.5 inches of water/foot of packing height.

31. The multistage scrubber of claim 28, wherein packing is comprised of austenetic stainless steel.

32. The multistage scrubber of claim 28, wherein the interior surface of the shell is comprised of rubber, glass, epoxy, stainless steel, zirconium, or Hastelloy C276.

33. The multistage scrubber of claim 27 further comprising a liquid repository, the liquid repository located within the interior cavity of the shell at the lower end of the shell.

34. The multistage scrubber of claim 27, wherein the liquid distributors comprise nozzles.

35. The multistage scrubber of claim 27, wherein the liquid distributors connected to the liquid distributor header of scrubber stage 1 comprise nozzles.

36. The multistage scrubber of claim 27, wherein each of the liquid distributor headers are perpendicular to the vertical axis of the shell.

37. The multistage scrubber of claim 27 further comprising:

N-1 number of tanks numbered from 2 to N, each tank having an interior surface and further having a fluid discharge port, each tank in fluid communication with the correspondingly numbered liquid distributor header; and

N number of liquor removal lines numbered from 1 to N, each of N liquor removal lines connected to the correspondingly numbered stage through at least one fluid exit port, such that a fluid path exists through each correspondingly numbered liquor removal line into the correspondingly numbered tank.

38. The multistage scrubber of claim 37, wherein the interior surface of each of the tanks is comprised of stainless steel, epoxy, rubber, or Hastelloy.

39. The multistage scrubber of claim 37 further comprising:

N number of water lines numbered 1 to N, each water line capable of providing fluid to the correspondingly numbered liquid distributor header;

N number of ammonia headers numbered 1 to N, each ammonia header capable of providing fluid to the correspondingly numbered liquid distribution header.

40. The multistage scrubber of claim 27 further comprising:

N-1 number of drain headers, where each drain header is capable of transferring fluid between a selected stage and at least one other stage.

41. The multistage scrubber of claim 40, wherein each of the drain headers is capable of transferring fluid from a selected stage and a lower numbered stage than the selected stage.

42. The multistage scrubber of claim 40, wherein the drain headers are numbered 2 to N-1, and further wherein n is an integer counter having a value of between 2 and N-1 (2, 3, 4...N-1), further wherein the n numbered drain header is capable of transferring fluid from the n numbered stage to the n-1 numbered stage.

43. The multistage scrubber of claim 40 further comprising a liquid repository, the liquid repository located within the interior cavity of the shell at the lower end of the shell, and wherein the drain headers are numbered 2 to N-1 and further wherein n is an integer counter having a value between 3 and N-1 (3, 4, 5...N-1), further wherein the n numbered drain header is capable of transferring fluid from the n numbered stage to the n-1

numbered stage, further wherein the number 2 drain header is capable of transferring fluid from the number 2 stage to the liquid repository.

44. A multistage scrubber for removing sulfur dioxide from flue gas comprising steps a-g from claim 27.

45. The multistage scrubber of claim 44, wherein each packing set is supported.

46. The multistage scrubber of claim 44, wherein the packing is wire gauze packing.

47. The multistage scrubber of claim 44, wherein the packing has a pressure drop of less than 0.5 inches of water/foot of packing height.

48. The multistage scrubber of claim 44, wherein packing is comprised of austenetic stainless steel.

49. A process for manufacturing thiosulfate comprising:

(a) providing a reactor feed stream comprising ammonium sulfite or ammonium bisulfite;

(b) flowing the reactor feed stream through a fluidized bed reactor containing solid sulfur;

(c) contacting the reactor feed stream with ammonia; and

(d) reacting the product feed stream, sulfur, and ammonia to form a thiosulfate product stream.

50. The process according to claim 49, wherein step (d) is performed at a reaction temperature of less than 243°F.

51. The process according to claim 49, wherein the solid sulfur is in pellet form.

52. The process according to claim 49, wherein the fluid velocity of the reactor feed stream through the fluidized bed of sulfur is less than 2 inches per second.

53. The process according to claim 52, wherein the fluid velocity of the reactor feed stream through the fluidized bed of sulfur is less than 1.5 inches per second.

54. The process according to claim 49, further comprising:

adding a molten sulfur make-up stream to the fluidized bed of sulfur.

55. The process according to claim 54, wherein the step of adding a molten sulfur make-up stream to the fluidized bed of sulfur is performed by spraying the molten sulfur through a nozzle.

56. The process according to claim 49, wherein the concentration of ammonium bisulfite in combination with ammonium sulfite in the thiosulfate product stream is less than 1%.

57. The process according to claim 56, wherein the concentration of ammonium bisulfite in combination with ammonium sulfite in the thiosulfate product stream is less than 0.1%.

58. The process according to claim 49, wherein concentration of dissolved solids in the thiosulfate product stream is greater than 55%.

59. The process according to claim 49, further comprising after step (d):

(e) removing a portion of the water from the thiosulfate product stream to form a discharge liquid.

60. The process according to claim 59, wherein the step of removing water from the thiosulfate product stream is accomplished by the use of a flash evaporator or quencher.

61. The process according to claim 59, further comprising:

(f) cooling the discharge liquid.

62. A thiosulfate reactor system comprising:

a fluidized bed reactor, the fluidized bed reactor having an interior cavity, an interior surface, an exterior surface, a circumference, a bottom portion, and an upper portion;

a bed of solid sulfur, the bed of solid sulfur being contained within the interior cavity of the fluidized bed reactor;

a reactor feed stream, the reactor feed stream being connected to the bottom portion of the fluidized bed reactor such that the fluid is capable of flowing from the thiosulfate supply line to the interior cavity of the fluidized bed reactor;

an ammonia feed line, the ammonia feed line being connected to the fluidized bed reactor such that fluid is capable of flowing from the ammonia feed line to the interior cavity of the fluidized bed reactor;

a sulfur feed line, the sulfur feed line being connected to the upper portion of the fluidized bed reactor such that fluid is capable of flowing from the sulfur feed line to the interior cavity of the fluidized bed reactor; and

a thiosulfate product line, the thiosulfate product line connected to the fluidized bed reactor such that fluid may be removed from the fluidized bed reactor.

63. The thiosulfate reactor system of claim 62, wherein the bed of solid sulfur comprises sulfur pellets.

64. The thiosulfate reactor system of claim 62, wherein the bed of solid sulfur is at a temperature of less than 243°F.

65. The thiosulfate reactor system of claim 62, wherein the interior surface of the fluidized bed reactor is comprised of stainless steel, epoxy, rubber, or Hastelloy.

66. The thiosulfate reactor system of claim 62, wherein the upper end of the fluidized bed reactor is an expanded section.

67. The thiosulfate reactor system of claim 62, further comprising:

a cooling jacket, external cooler, or internal coils, the cooling jacket, external cooler or internal coil disposed, such that the cooling jacket, external cooler or internal coil is capable of cooling the bed of solid sulfur.

68. The thiosulfate reactor system of claim 67, wherein the cooling jacket is capable of circulating brine, refrigerant, or cooling water.

69. The thiosulfate reactor system of claim 62, further comprising a flash evaporator or quencher, the flash evaporator or quencher connected to the thiosulfate product line such that the flash evaporator or quencher is capable of removing water from the thiosulfate product line.

70. A thiosulfate production system comprising:

(a) a vertically-oriented shell, the shell having an upper end and a lower end, the shell further having a flue gas entry port and flue gas exit port, the shell further having an interior cavity, a vertical axis and an interior surface, and a diameter;

(b) N number of liquid distributor headers within the interior cavity of the shell, so located such that the liquid distributor headers are capable of receiving fluid, wherein N is greater than 1 and wherein the liquid distribution headers are numbered from 1 to N;

(c) a plurality of liquid distributors, the liquid distributors in fluid communication with the liquid distributor headers and capable of distributing fluid from the liquid distributor headers to the interior cavity of the shell;

(d) N-1 number of scrubber stage separators numbered 2 to N, along the vertical axis, each of the scrubber stage separators located in a plane substantially perpendicular to the vertical axis, each scrubber stage separator having an upper surface;

(e) a plurality of fluid exit ports, each fluid exit port capable of withdrawing liquid from the upper surface of a particular scrubber stage separator;

(f) N number of stages numbered 1 to N, wherein each of the stages numbered 2 to N comprise the correspondingly numbered liquid distribution header, the correspondingly numbered scrubber stage separator, and at least one of the fluid exit ports, and stage 1 comprises the correspondingly numbered liquid distributor header and at least one fluid exit port;

(g) a scrubber product line, the scrubber product line capable of removing fluid from the multistage scrubber;

(h) a fluidized bed reactor, the fluidized bed reactor having an interior cavity, an interior surface, an exterior surface, a circumference, a bottom portion and an upper portion;

(i) a bed of solid sulfur, the bed of solid sulfur being contained within the interior cavity of the fluidized bed reactor;

(j) a reactor feed stream, the thiosulfate supply line being connected to the scrubber product line and to the bottom portion of the fluidized bed reactor such

that the fluid is capable of flowing from the scrubber product line through the reactor feed line to the interior cavity of the fluidized bed reactor;

(k) an ammonia feed line, the ammonia feed line being connected to the fluidized bed reactor such that fluid is capable of flowing from the ammonia feed line to the interior cavity of the fluidized bed reactor;

(l) a sulfur feed line, the sulfur feed line being connected to the upper portion of the fluidized bed reactor such that fluid is capable of flowing from the sulfur feed line to the interior cavity of the fluidized bed reactor; and

(m) a thiosulfate product line, the thiosulfate product line connected to the fluidized bed reactor such that fluid may be removed from the fluidized bed reactor.

71. The multistage scrubber of claim 70 further comprising packing, the packing arranged within the interior cavity of the shell, the packing located above at least one scrubber stage separator.

72. The multistage scrubber of claim 71, wherein the packing is wire gauze packing.

73. The multistage scrubber of claim 71, wherein the packing has a pressure drop of less than 0.5 inches of water/foot of packing height.

74. The multistage scrubber of claim 71, wherein packing is comprised of austenetic stainless steel.

75. The multistage scrubber of claim 70, wherein the interior surface of the shell is comprised of rubber, glass, epoxy, stainless steel, zirconium, or Hastelloy C276.

76. The multistage scrubber of claim 70, further comprising a liquid repository, the liquid repository located within the interior cavity of the shell at the lower end of the shell.

77. The multistage scrubber of claim 70, wherein the liquid distributors comprise nozzles.

78. The multistage scrubber of claim 70, wherein the liquid distributors connected to the liquid distributor header of scrubber stage 1 comprise nozzles.

79. The multistage scrubber of claim 70 further comprising:

N-1 number of tanks numbered from 2 to N, each tank having an interior surface and further having a fluid discharge port, each tank in fluid communication with the correspondingly numbered liquid distributor header; and

N number of liquor removal lines numbered from 1 to N, each of the N liquor removal lines connected to the correspondingly numbered stage through at least one fluid exit port, such that a fluid path exists through each correspondingly numbered liquor removal line, into the correspondingly numbered tank.

80. The multistage scrubber of claim 79, wherein the interior surface of each of the tanks is comprised of stainless steel, epoxy, rubber, or Hastelloy.

81. The multistage scrubber of claim 79 further comprising:

N number of water lines numbered 1 to N, each water line capable of providing fluid to the correspondingly numbered liquid distributor header; and

N number of ammonia headers numbered 1 to N, each ammonia header capable of providing fluid to the correspondingly numbered liquid distributor header.

82. The multistage scrubber of claim 81, wherein each of the drain headers is capable of transferring fluid from a selected stage to a lower numbered stage than the selected stage.

83. The multistage scrubber of claim 81, wherein the drain headers are numbered 2 to N-1, and further wherein n is an integer counter having a value of between 2 and N-1 (2, 3, 4...N-1), further wherein the n numbered drain header is capable of transferring fluid from the n numbered stage to the n-1 numbered stage.

84. The multistage scrubber of claim 81, further comprising a liquid repository, the liquid repository located within the interior cavity of the shell at the lower end of the shell, and wherein the drain headers are numbered 2 to N-1 and further wherein n is an integer counter having a value between 3 and N-1 (3, 4, 5...N-1), further wherein the n numbered drain header is capable of transferring fluid from the n numbered stage to the n-1 numbered liquid, further wherein the number 2 drain header is capable of transferring fluid from the number 2 stage to the liquid repository.

85. The thiosulfate reactor system of claim 70, wherein the bed of solid sulfur comprises sulfur pellets.

86. The thiosulfate reactor system of claim 70, wherein the bed of solid sulfur is at a temperature of less than 243°F.

87. The thiosulfate reactor system of claim 70, wherein the interior surface of the fluidized bed reactor is comprised of stainless steel, epoxy, rubber, or Hastelloy

88. The thiosulfate reactor system of claim 70, wherein the upper end of the fluidized bed reactor is an expanded vapor section.

89. The thiosulfate reactor system of claim 70, further comprising:

a cooling jacket, external cooler, or internal coils, the cooling jacket, external cooler or internal coil disposed, such that the cooling jacket, external cooler or internal coil is capable of cooling the bed of solid sulfur.

90. The thiosulfate reactor system of claim 89, wherein the cooling jacket is capable of circulating brine, refrigerant, or cooling water.

91. The thiosulfate reactor system of claim 89, further comprising a flash evaporator or quencher, the flash evaporator or quencher connected to the thiosulfate product line such that the flash evaporator or quencher is capable of removing water from the thiosulfate product line.

92. A method for manufacturing thiosulfate from a flue gas stream, the flue gas stream having an initial sulfur dioxide concentration, comprising the following steps:

(a) contacting the flue gas stream with a plurality of aqueous ammonia liquor streams;

(b) forming a scrubber product stream scrubber product stream comprising ammonium bisulfite and ammonium sulfite;

(c) flowing the scrubber product stream through a fluidized bed reactor containing solid sulfur; and

(d) contacting the reactor feed stream with ammonia; and

(e) reacting the scrubber product feed stream, sulfur and ammonia to form a thiosulfate product stream.

93. The method as described in claim 92 further comprising:

forming each of the aqueous ammonia liquor streams by combining a water stream and an ammonia stream.

94. The method as described in claim 92, wherein each of the aqueous ammonia liquor streams has a pH of between 5.0 and 6.0.

95. The method as described in claim 94, wherein each of the aqueous ammonia liquor streams has a pH of between 5.4 and 5.8.

96. The method of claim 92, wherein contacting the flue gas stream with a plurality of aqueous ammonia liquor streams is accomplished through the use of liquid distributors.

97. The method of claim 96, wherein the liquid distributors are nozzles.

98. The method as described in claim 92, wherein the total dissolved solids of the scrubber product stream are about 50 to about 90% ammonium bisulfite, by weight.

99. The method as described in claim 92, wherein the total dissolved solids of the scrubber product stream are about 5 to about 45% sulfite, by weight.

100. The method as described in claim 92, further comprising after contacting the flue gas stream with a plurality number of aqueous ammonia liquor streams:

producing a flue gas effluent stream, the flue gas effluent stream having a final sulfur dioxide concentration.

101. The method as described in claim 100, wherein the flue gas effluent stream has a final sulfur dioxide concentration of less than 100 ppm by weight.

102. The method as described in claim 100, wherein the flue gas effluent stream has a final sulfur dioxide concentration of less than 1% of the flue gas initial sulfur dioxide concentration.

103. The process according to claim 92, wherein step (e) is performed at a reaction temperature of less than 243°F.

104. The process according to claim 92, wherein the solid sulfur is in pellet form.

105. The process according to claim 92, wherein the fluid velocity of the reactor feed stream through the fluidized bed of sulfur is less than 2 inches per second.

106. The process according to claim 105, wherein the fluid velocity of the reactor feed stream through the fluidized bed of sulfur is less than 1.5 inches per second.

107. The process according to claim 92, further comprising:

adding a molten sulfur make-up stream to the fluidized bed of sulfur.

108. The process according to claim 107, wherein the step of adding a molten sulfur make-up stream to the fluidized bed of sulfur is performed by spraying the molten sulfur through a nozzle.

109. The process according to claim 92, wherein the concentration of ammonium bisulfite in combination with ammonium sulfite in the thiosulfate product stream is less than 1%.

110. The process according to claim 109, wherein the concentration of ammonium bisulfite in combination with ammonium sulfite in the thiosulfate product stream is less than 0.1%.

111. The process according to claim 92, wherein concentration of dissolved solids in the thiosulfate product stream is greater than 55%.

112. The process according to claim 92, further comprising after step (d):
(e) removing a portion of the water from the thiosulfate product stream to form a discharge liquid.

113. The process according to claim 112, wherein the step of removing water from the thiosulfate product stream is accomplished by the use of a flash evaporator or quencher.

114. The process according to claim 113, further comprising:

(f) cooling the discharge liquid.

115. A method for manufacturing a scrubber product stream comprising ammonium sulfite or ammonium bisulfite comprising:

(a) providing a multistage scrubber for removing sulfur dioxide from flue gas comprising a vertically-oriented shell, the shell having an upper end and a lower end, the shell further having a flue gas entry port and flue gas exit port, the shell further having an interior cavity, a vertical axis, and an interior surface; N number of liquid distributor headers within the interior cavity of the shell, so located such that the liquid distributor headers are capable of receiving fluid, wherein N is greater than 1 and wherein the liquid distribution headers are numbered from 1 to N; a plurality of liquid distributors, the liquid distributors in fluid communication with the liquid distributor headers and capable of distributing fluid from the liquid distributor headers to the interior cavity of the shell; N-1 number of scrubber stage separators numbered 2 to N along the vertical axis, each of the

scrubber stage separators located in a plane substantially perpendicular to the vertical axis, each scrubber stage separator having an upper surface; a plurality of fluid exit ports, each fluid exit port capable of withdrawing liquid from the upper surface of a particular scrubber stage separator; N number of stages numbered 1 to N wherein each of the stages numbered 2 to N comprise the correspondingly numbered liquid distribution header, the correspondingly numbered scrubber stage separator, and at least one of the fluid exit ports and stage 1 comprises the correspondingly numbered liquid distribution header and at least one fluid exit port; a scrubber product line, the scrubber product line capable of removing fluid from the multistage scrubber;

(b) supplying a flue gas stream comprising sulfur dioxide;

(c) supplying an ammonia stream;

(d) supplying a water stream; and

(e) reacting the water stream, ammonia stream and sulfur dioxide within the multistage scrubber to form a scrubber product stream, the product stream comprising ammonium sulfite or ammonium bisulfite.

116. A method for manufacturing a thiosulfate product stream comprising ammonium thiosulfate comprising:

(a) providing a thiosulfate reactor system comprising a fluidized bed reactor, the fluidized bed reactor having an interior cavity, an interior surface, an exterior surface, a circumference, a bottom portion and an upper portion; a bed of solid sulfur, the bed of solid sulfur being contained within the interior cavity of the fluidized bed reactor; a reactor feed stream, the reactor feed stream being connected to the bottom portion of

the fluidized bed reactor such that the fluid is capable of flowing from the reactor feed stream to the interior cavity of the fluidized bed reactor; an ammonia feed line, the ammonia feed line being connected to the fluidized bed reactor such that fluid is capable of flowing from the ammonia feed line to the interior cavity of the fluidized bed reactor; a sulfur feed line, the sulfur feed line being connected to the upper portion of the fluidized bed reactor such that fluid is capable of flowing from the sulfur feed line to the interior cavity of the fluidized bed reactor; and a thiosulfate product line, the thiosulfate product line connected to the fluidized bed reactor such that fluid may be removed from the fluidized bed reactor;

(b) supplying an ammonium bisulfite or ammonium sulfite stream;

(c) supplying a sulfur stream;

(d) supplying an ammonia stream; and

(e) reacting the sulfur stream, ammonia stream and ammonium bisulfite or ammonium sulfite stream within the thiosulfate reactor system to form a thiosulfate product stream comprising ammonium thiosulfate.

117. A method for manufacturing a thiosulfate product stream comprising ammonium thiosulfate comprising:

(a) providing a multistage scrubber for removing sulfur dioxide from flue gas comprising a vertically-oriented shell, the shell having an upper end and a lower end, the shell further having a flue gas entry port and flue gas exit port, the shell further having an interior cavity, a vertical axis, and an interior surface; N number of liquid distributor headers within the interior cavity of the shell, so located such that the liquid distributor headers are

capable of receiving fluid, wherein N is greater than 1 and wherein the liquid distribution headers are numbered from 1 to N; a plurality of liquid distributors, the liquid distributors in fluid communication with the liquid distributor headers and capable of distributing fluid from the liquid distributor headers to the interior cavity of the shell; N-1 number of scrubber stage separators numbered 2 to N along the vertical axis, each of the scrubber stage separators located in a plane substantially perpendicular to the vertical axis, each scrubber stage separator having an upper surface; a plurality of fluid exit ports, each fluid exit port capable of withdrawing liquid from the upper surface of a particular scrubber stage separator; N number of stages numbered 1 to N wherein each of the stages numbered 2 to N comprise the correspondingly numbered liquid distribution header, the correspondingly numbered scrubber stage separator, and at least one of the fluid exit ports and stage 1 comprises the correspondingly numbered liquid distribution header and at least one fluid exit port; a scrubber product line, the scrubber product line capable of removing fluid from the multistage scrubber;

(b) providing a thiosulfate reactor system comprising a fluidized bed reactor, the fluidized bed reactor having an interior cavity, an interior surface, an exterior surface, a circumference, a bottom portion, and an upper portion; a bed of solid sulfur, the bed of solid sulfur being contained within the interior cavity of the fluidized bed reactor; a reactor feed stream, the reactor feed stream being connected to the scrubber product line and bottom portion of the fluidized bed reactor such that the fluid is capable of flowing from the scrubber product line through the reactor feed stream to the interior cavity of the fluidized bed reactor; an ammonia feed line, the ammonia feed line being connected to

the fluidized bed reactor such that fluid is capable of flowing from the ammonia feed line to the interior cavity of the fluidized bed reactor; a sulfur feed line, the sulfur feed line being connected to the upper portion of the fluidized bed reactor such that fluid is capable of flowing from the sulfur feed line to the interior cavity of the fluidized bed reactor; and a thiosulfate product line, the thiosulfate product line connected to the fluidized bed reactor such that fluid may be removed from the fluidized bed reactor;

(c) supplying a flue gas stream comprising sulfur dioxide;

(d) supplying a first ammonia stream;

(e) supplying a water stream;

(f) reacting the water stream, the first ammonia stream and sulfur dioxide within the multistage scrubber to form a scrubber product stream, the product stream comprising ammonium sulfite or ammonium bisulfite;

(g) supplying a sulfur stream;

(h) supplying a second ammonia stream; and

(i) reacting the sulfur stream, the second ammonia stream, and the scrubber product stream within the thiosulfate reactor system to form a thiosulfate product stream comprising ammonium thiosulfate.